GAWI
Journal of Action Research
Vol. 6 No. 1 2026

Enhancing Students' Higher-Order Thinking Skills Through Web-Based Learning with Multiple Representations in Biology Education

Toto Sutarto Gani Utari[1*], Cita Tresnawati[1], and Mimi Halimah[1]

[1]Biology Education Study Program, Faculty of Teacher Training and Education, Universitas Pasundan, Bandung, Indonesia.
*ganiutari@unpas.ac.id

Received	Accepted	Published
02/06/2026	03/07/2026	31 Juli 2026

DOI
10.59329/gawi.v6i1.329

ABSTRACT

In the digital era, the development of higher-order thinking skills (HOTS) has become one of the major challenges in education, particularly in biology, which requires students to understand complex concepts. This study aimed to analyze students' higher-order thinking skills (HOTS) through web-based learning integrated with multiple representations in biology education in Bandung, Indonesia. This study employed a one-group pretest–posttest design involving Grade 10 and Grade 11 science-track students selected through purposive sampling from five senior high schools in Bandung, Indonesia. The research instrument consisted of a test comprising both multiple-choice and essay questions. The findings revealed that cognitive ability was the most prominent HOTS dimension, followed by logical analysis, problem-solving, critical thinking, and creative thinking skills. These results indicate that web-based learning integrated with multiple representations can facilitate students' understanding of biological concepts more effectively. The presentation of various visual representations, including images, three-dimensional animations, videos, tables, diagrams, and graphs, along with case-study features, helped transform abstract content into more concrete and structured forms, thereby strengthening higher-order thinking skills. The findings further suggest that multiple representations enable students to understand biological phenomena from multiple perspectives, critically evaluate information, and apply conceptual knowledge to solve complex problems.

Keywords: biology education, cognitive skills, higher-order thinking skills (hots), multiple representations, web-based learning

How to cite:
Utari, T. S. G., Tresnawati, C., & Halimah, M. (2017). Enhancing Students' Higher-Order Thinking Skills Through Web-Based Learning with Multiple Representations in Biology Education. *Gawi: Journal of Action Research*, *6(1)*, 103-110

INTRODUCTION

Developing higher-order thinking skills (HOTS) has become a significant challenge for educators in the digital era, where the rapid growth of information and increasing complexity of knowledge demand more advanced cognitive abilities, while students' thinking skills often remain underdeveloped. The 2022 Program for International Student Assessment (PISA) results indicate that Indonesian students demonstrate relatively low levels of critical and creative thinking skills, particularly in science. This finding suggests that educational practices in Indonesia continue to emphasize memorization and basic comprehension, with insufficient attention given to the development of HOTS (OECD, 2023). Furthermore, PISA data reveal that only 18% of Indonesian students achieved at least Level 2 proficiency in mathematics, considerably lower than the OECD average of 69% (OECD, 2023). Previous studies have shown that many schools in Indonesia still focus primarily on teaching fundamental concepts and factual knowledge, while opportunities for students to engage in critical thinking and problem-solving activities remain limited. Consequently, students are often inadequately prepared to apply their knowledge. Another factor hindering the development of higher-order thinking skills in Indonesia is the limited readiness of the educational system, including the relatively low quality of instruction and the mismatch between students' learning outcomes and the competencies required in the workforce (Madhakomala et al., 2022). In addition, the underutilization of educational technology, particularly technology that is effectively integrated with pedagogical approaches designed to foster students' thinking abilities, remains a significant barrier to HOTS development (Liani, 2025).

Students frequently encounter various challenges when learning biology as a scientific discipline, including misconceptions, cognitive biases, and difficulties in understanding complex and abstract concepts (Ogundeji et al., 2025; Ikhsan et al., 2025) In particular, students often struggle to comprehend hierarchical relationships within biological systems (e.g., cells → tissues → organs → organ systems), especially at the cellular level. They may misinterpret biological processes and fail to recognize the interconnectedness among organ systems, resulting in fragmented rather than integrated understanding of biological concepts (Kostas & Reiss, 2018). Other studies have reported that students frequently fail to connect scientific methods and concepts with real-world contexts (Osborne & Dillon, 2010). Furthermore, scientific concepts are often presented in textbooks as isolated facts to be memorized rather than as interconnected knowledge requiring deep conceptual understanding (Murtonen et al., 2020). Consistent with these findings Kottmeyer et al., (2020) reported that biology students demonstrate limited diagrammatic literacy, as evidenced by difficulties in interpreting conventional diagrammatic elements such as numbering systems and symbolic labels used to represent objects, visualizing cross-sectional views and magnified internal structures, and recognizing and managing multiple diagrammatic conventions simultaneously. These challenges may hinder students' ability to construct meaningful scientific understanding and apply biological knowledge effectively.

Digital-assisted learning has brought significant changes to students' learning development. Several studies have demonstrated that digital learning environments can transform the way students think and act more effectively (Tresnawati, 2022). Such approaches have been shown to enhance decision-making and problem-solving abilities while supporting cognitive processes (Tresnawati, 2024). In addition, digital learning can promote the development of critical thinking, problem-solving skills, and self-reflection on students' own thinking processes, thereby fostering higher levels of cognitive engagement (Blyznyuk & Kachak, 2024).

Biology is a unique discipline because understanding biological phenomena comprehensively requires consideration of four levels of representation: (1) the macroscopic level, (2) the cellular or subcellular (microscopic) level, (3) the molecular (submicroscopic) level, and (4) the symbolic level (Van Meter et al., 2020). Visual representations enable students to connect information in more concrete and accessible ways, thereby facilitating conceptual understanding (Thyberg et al., 2024). The use of multiple representations in biology learning also promotes deeper and more holistic understanding of complex concepts, such as mitosis and meiosis. Through diverse forms of visual representation, including diagrams, illustrations, and animations, students can more

effectively integrate and relate different aspects of the topics being studied, leading to enhanced conceptual comprehension (Hansen & Richland, 2020).

Despite extensive research demonstrating the effectiveness of multimedia learning, multiple representations, and web-based learning in science education, studies integrating macroscopic, microscopic, sub-microscopic, and symbolic representations within a single web-based learning platform to support the development of Higher-Order Thinking Skills (HOTS) remain limited. Furthermore, reports on the implementation of such integrated approaches at the senior high school level in Indonesia are still scarce. Therefore, the novelty of this study lies in the development and implementation of a web-based biology learning environment that integrates the four levels of biological representation into a unified framework to facilitate the enhancement of students' HOTS, as measured through various higher-order thinking skill indicators.

Based on the challenges outlined above, this study focuses on web-based biology learning designed to help students understand complex biological concepts while providing flexible access to learning materials anytime and anywhere. Accordingly, the study aims to analyze students' Higher-Order Thinking Skills (HOTS) through web-based learning integrated with multiple representations in biology education in Bandung, Indonesia. The findings are expected to provide empirical evidence for the development of technology-enhanced biology learning strategies that effectively connect multiple levels of biological representation while fostering students' higher-order thinking skills. In addition, the study is expected to contribute to the advancement of more effective biology instruction that supports HOTS development and to serve as a reference for educators in designing web-based learning environments that integrate multiple representations to enhance students' conceptual understanding and cognitive performance.

METHODS

This study employed an experimental method using a one-group pretest–posttest design to investigate students' Higher-Order Thinking Skills (HOTS) through web-based biology learning integrated with multiple representations. Participants were selected using purposive sampling based on several criteria, including the suitability of the classes for the instructional content under investigation, relatively homogeneous prior academic achievement, and the schools' readiness to support the implementation of web-based learning. This sampling technique was adopted to ensure the selection of participants who were relevant to the objectives of the study. The participants consisted of 125 science-track students from five senior high schools in Bandung, Indonesia, including 75 Grade 10 students and 50 Grade 11 students. Demographic variables such as age and gender were not included in the analysis because the study focused on learning outcomes at the class level, and participants were drawn from relatively homogeneous grade cohorts.

The intervention was conducted over two instructional sessions, each lasting 90 minutes. The learning topics included the digestive system, respiratory system, and immune system. Instruction was delivered through a web-based learning platform integrating macroscopic, microscopic, sub-microscopic, and symbolic representations of biological concepts. Students accessed the learning materials using laptops or smartphones connected to the internet, while teachers served as facilitators throughout the learning process.

The research instrument consisted of 30 multiple-choice items designed to assess students' cognitive abilities and 19 essay questions intended to measure higher-order thinking skills. The essay section comprised five items assessing critical thinking, four items assessing creative thinking, five items evaluating problem-solving skills, and five items measuring logical analytical thinking. Content validity for each HOTS dimension was established through expert judgment by two biology education specialists to ensure the relevance and appropriateness of the instrument items.

Pretest and posttest data were analyzed using descriptive statistics to examine students' higher-order thinking skills before and after the intervention. To determine whether the intervention produced significant improvements, a paired-samples t-test was conducted to compare students' pretest and posttest scores within the same group. This analysis was performed to identify

significant differences in students' higher-order thinking skills following participation in the web-based learning program integrated with multiple representations.

RESULT AND DISCUSSION

Students' Higher-Order Thinking Skills (HOTS) were evaluated using N-gain analysis to determine the extent of improvement following the implementation of web-based learning integrated with multiple representations. The N-gain results for senior high school students in Bandung are presented in Table 1.

Table 1 N-Gain scores for each higher order thinking skills (HOTS) dimension

HOTS dimension	N-gain	Category
Cognitive	0.78	High
Logical Analysis	0.69	Medium
Problem Solving	0.60	Medium
Critical	0.58	Medium
Creative	0.58	Medium

Table 1 shows varying levels of improvement across the different HOTS dimensions. The cognitive dimension exhibited the highest gain (g = 0.78), whereas logical analysis, problem-solving, critical thinking, and creative thinking demonstrated moderate improvements (g = 0.58–0.69). These findings suggest that web-based learning integrated with multiple representations is particularly effective in facilitating students' conceptual understanding compared with higher-order cognitive processes that require analysis, evaluation, creation, and complex problem-solving.

The results indicate that web-based learning employing a multiple-representation approach can facilitate cognitive development and support the overall enhancement of students' Higher-Order Thinking Skills (HOTS). The integration of diverse representations, including text, images, diagrams, symbols, three-dimensional animations, and case-study features, helped students develop a more comprehensive understanding of biological concepts. Through exposure to multiple representations, students not only acquired information but also connected different forms of representation to construct deeper and more meaningful conceptual understanding. Furthermore, this learning approach creates a supportive digital learning environment in which students can access learning materials through smartphones, thereby extending learning opportunities beyond the classroom.

The higher gain observed in the cognitive dimension compared with the other HOTS dimensions suggests that the use of multiple representations effectively supports the processes of remembering, understanding, applying, and analyzing biological concepts through the presentation of information in diverse representational formats. These representations assist students in integrating information, establishing relationships among concepts, and reducing the complexity of abstract biological content. Consequently, web-based learning not only strengthens conceptual mastery but also facilitates the development of more systematic and transferable knowledge structures that can be readily applied in different learning contexts.

These findings are consistent with the study by Masriat & Laksono, (2025) which demonstrated that multiple-representation-based learning enhances students' conceptual understanding and mastery of subject matter. This approach also helps identify and correct misconceptions while strengthening the long-term retention of biological concepts (Van Meter et al., 2020). This may be attributed to the ability of multiple representations to facilitate information integration across different representational formats, making abstract concepts easier to understand than when presented through a single representation (Treagust et al., 2013) Mayer (2009). Furthermore, Parong & Mayer, (2021) reported that immersive virtual reality (IVR) can enhance student engagement by providing more meaningful learning experiences, although its

benefits may be limited when virtual environments impose excessive cognitive load that hinders effective information processing.

Figure 1 illustrates the features of the web-based learning platform integrating multiple representations in biology instruction.

Figure 1. Display of material in a web-based Multiple representation

The dimensions of logical analysis, problem-solving, critical thinking, and creative thinking demonstrated moderate gains with a tendency toward the high category. These findings indicate that web-based learning integrated with multiple representations not only supports conceptual mastery but also facilitates higher-order thinking processes through the integration of visual, microscopic, macroscopic, and interactive representations. Furthermore, the presentation of information through images, three-dimensional animations, videos, tables, diagrams, graphs, and case studies encourages students to evaluate information from multiple perspectives, connect evidence with scientific concepts, and develop alternative solutions to biological problems. Such learning conditions contribute to the development of critical thinking skills, including classification, evidence-based justification, drawing conclusions, and applying problem-solving strategies in a more systematic manner. In addition, students' engagement in interpreting and transforming multiple forms of representation supports the development of logical analysis and idea generation, both of which are essential components of creative thinking and problem-solving in biology learning.

Logical analysis exhibited a relatively higher gain compared with most other HOTS dimensions. This finding suggests that students became increasingly capable of identifying relationships among concepts, distinguishing relevant from irrelevant information, engaging in logical reasoning, and constructing arguments. The improvement in logical analysis may be attributed to the characteristics of multiple representations, which present concepts through various formats such as text, images, diagrams, and animations. The diversity of these representations enables students to compare information from different perspectives before constructing their own understanding.

The findings of this study reveal that multiple representations promote the development of higher-order thinking skills, including the analysis and synthesis of information, which are essential competencies in the 21st-century education (Diani et al., 2024). The use of multimodal representations, such as images, videos, written text, and spoken language, enables learners to develop the ability to construct more coherent explanations that are appropriate for different audiences while facilitating deeper and more structured learning processes (Nielsen et al., 2020). In the context of biology education, these competencies are particularly important because many biological concepts are abstract in nature and require students to understand complex cause-and-effect relationships among biological processes.

Problem-solving skills demonstrated gains within the moderate category. This finding indicates that students became increasingly capable of identifying problems, analyzing relevant information, and determining appropriate solutions based on the biological concepts they had learned. The improvement in problem-solving skills may be attributed, in part, to the use of multiple representations that incorporated case-study features, enabling students to examine the relationships among concepts, data, and real-world problems before formulating solutions.

These findings provide further evidence that the presentation of authentic problems through case-based learning can facilitate the development of students' problem-solving abilities. Students' engagement in analyzing situations, evaluating alternative solutions, and making evidence-based decisions promotes the development of cognitive and critical thinking skills that serve as essential foundations for effective problem-solving (Ahmar et al., 2023; Siswati & Suratno, 2023). Furthermore, sustained engagement in problem-solving activities has been shown to contribute to improved academic achievement and the development of higher-order thinking skills (Nikolić & Antonijević, 2024). In biology education, problem-solving skills are particularly important because many biological phenomena cannot be fully understood through rote memorization alone but require the analysis of relationships among variables and the application of conceptual knowledge to complex situations.

The findings of this study are consistent with previous research demonstrating the effectiveness of innovative learning approaches in promoting HOTS. Case-Based Learning has been shown to significantly improve Biology students' Higher-Order Thinking Skills, reaching a high category, particularly in the dimension of creativity and knowledge generation (Wikanta & Susilo, 2022)

Similarly, a systematic review by Primahesa et al., (2023) confirmed that constructivist learning approaches and the use of interactive multimedia effectively stimulate students' HOTS development. Furthermore, Multiple Representations (MR)-based instruction has been found to be significantly more effective in enhancing critical thinking skills, fostering positive attitudes, and encouraging active student engagement, particularly in the physics education (Ogunyemi et al., 2025). In biology learning, critical and creative thinking skills are especially important because many biological phenomena involve complex cause-and-effect relationships and require students to evaluate information from multiple sources before drawing scientific conclusions.

Figure 2 illustrates students' learning activities while using the web-based learning platform integrated with multiple representations.

Figure 2. Student learning activities through web-based multiple representations

Therefore, multiple representations serve not only as a means of presenting information but also as a form of cognitive scaffolding that supports knowledge integration and the development of various dimensions of Higher-Order Thinking Skills (HOTS) in understanding complex biological phenomena.

CONCLUSION

This study demonstrates that web-based learning integrated with multiple representations is effective in facilitating the development of students' Higher-Order Thinking Skills (HOTS) in biology education. Improvements observed in the cognitive, logical analysis, problem-solving, critical thinking, and creative thinking dimensions indicate that the integration of visual, verbal, and interactive representations supports knowledge construction and deeper conceptual processing. These findings suggest that multiple representations help students understand biological phenomena from multiple perspectives, evaluate information more critically, and apply biological concepts to solve complex problems. In addition to strengthening conceptual understanding, the use of multiple representations contributes to the development of evidence-based reasoning, creativity, and problem-solving skills. Therefore, web-based learning integrated with multiple representations has considerable potential as an effective instructional strategy for fostering HOTS in 21st-century biology education. Future research is recommended to explore the effectiveness of multiple representations across different biology topics and to investigate their effects on specific dimensions of Higher-Order Thinking Skills in greater depth. Further studies should employ experimental designs involving control groups and longer implementation periods to provide stronger evidence regarding the effectiveness of this instructional approach.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES

Ahmar, D. S., Azzajjad, M. F., & Ahmar, A. S. (2023). Adapting to change: the effects of case study approaches on problem-solving skills. *ARRUS Journal of Mathematics and Applied Science*, *3*(2), 97–108.

Blyznyuk, T., & Kachak, T. (2024). Benefits of interactive learning for students' critical thinking skills improvement. *Journal of Vasyl Stefanyk Precarpathian National University*, *11*(1), 94–102. https://doi.org/10.15330/jpnu.11.1.94-102

Diani, R., Lengkana, D., Jalmo, T., Destiana, Al., Saregar, A., & Putra, F. G. (2024). Trends, challenges, and opportunities of multiple representation in science learning: a systematic literature review. *Review of Science, Mathematics and ICT Education*, *18*(1), 29–52.

Hansen, J., & Richland, L. E. (2020). Teaching and learning science through multiple representations: Intuitions and executive functions. *CBE Life Sciences Education*, *19*(4), 1–15. https://doi.org/10.1187/cbe.19-11-0253

Ikhsan, M., Kuswanto, H., Afkarina, N., & Dini, I. (2025). *What are the Misconceptions that occur to Students in Science Learning in Indonesia? A Systematic Literature Review*. *7*(1).

Kostas, K., & Reiss, J. M. (eds). (2018). Teaching biology in schools: global research, issues, and trends. In *Routledge: Vol. o*. Routledge. https://doi.org/10.4324/9781315110158

Kottmeyer, A. M., Meter, P. Van, & Cameron, C. (2020). Diagram comprehension ability of college students in an introductory biology course. *Advances in Physiology Education*, *44*(2), 169–180. https://doi.org/10.1152/ADVAN.00146.2018

Liani, A. M. (2025). Meta-Analisis Dampak Inovasi Pembelajaran pada penelitian pendidikan terhadap kemampuan berpikir tingkat tinggi (HOTS). *Jurnal Ilmiah Matematika (JIMAT)*, *6*(2), 714–723.

Madhakomala, R., Hakim, M. A., & Syifauzzuhrah, N. (2022). Problems of education in indonesia and alternative solutions. *International Journal of Business, Law, and Education*, *3*(2), 135–144.

Masriat, E., & Laksono, E. W. (2025). Pembelajaran berkelanjutan dengan inkuiri terbimbing berbasis multiple representation terhadap pemahaman konsep dan efikasi diri. *Jurnal Pendidikan Matematika Dan Sains*, *13*, 211–225.

Mayer, R. E. (2009). *Multimedia learning (2nd ed.)*. Cambridge University Press. https://doi.org/10.1017/CBO9780511811678

Murtonen, M., Nokkala, C., & Södervik, I. (2020). Challenges in understanding meiosis: fostering

metaconceptual awareness among university biology students. *Journal of Biological Education*, *54*(1), 3–16. https://doi.org/10.1080/00219266.2018.1538016

Nielsen, W., Turney, A., Georgiou, H., & Jones, P. (2020). Working with multiple representations: preservice teachers' decision-making to produce a digital explanation. *Learning: Research and Practice*, *6*(1), 51–69. https://doi.org/10.1080/23735082.2020.1750673

Nikolić, N., & Antonijević, R. (2024). Problem-solving in biology teaching: students' activities and their achievement. *International Journal of Science and Mathematics Education*, *22*(4), 765–785. https://doi.org/10.1007/s10763-023-10407-5

OECD. (2023). *PISA 2022 Results: The State of Learning and Equity in Education: Vol. I*. OECD Publishing. https://doi.org/10.1787/53f23881-en. ISBN

Ogundeji, O. M., Bungudu, A. R., & Ibrahim, A. (2025). *Exploring students ' misconceptions of science concepts in secondary school biology in Gusau, Zamfara State*. *3*(1), 1–10. https://doi.org/10.62672/joease.v3i1.42

Ogunyemi, T., Akintoye, H., & Owolabi, T. (2025). Multiple representations as tools for enhancing students' critical thinking and attitudes towards physics. *Faculty of Natural and Applied Sciences Journal of Mathematics, and Science Education*, *6*(4), 1–15.

Osborne, J., & Dillon, J. (Eds). (2010). Good practice in science teaching: what research has to say. In *McGraw-Hill Education* (Vol. 131, Issue 3315). https://doi.org/10.1038/131686b0

Parong, J., & Mayer, R. E. (2021). Cognitive and affective processes for learning science in immersive virtual reality. *Journal of Computer Assisted Learning*, *37*(1), 226–241. https://doi.org/10.1111/jcal.12482

Primahesa, A., Sajidan, & Ramli, M. (2023). Improving higher order thinking skills in high school biology: A systematic review. *Biosfer: Jurnal Pendidikan Biologi*, *16*(1), 206–218.

Siswati, B. H., & Suratno. (2023). The contribution of cognitive ability and critical thinking skills on the problem-solving skills of biology education profession students using case method learning. *Biosfer: Jurnal Pendidikan Biologi*, *16*(2), 419–426.

Thyberg, A., Schönborn, K., & Gericke, N. (2024). Investigating students' meaning-making of multiple visual representations of epigenetics at different levels of biological organisation. *International Journal of Science Education*, *46*(14), 1405–1431. https://doi.org/10.1080/09500693.2023.2289175

Treagust, D. F., Tsui, C. Y., & (Eds.). (2013). Multiple representations in biological education. In *Springer*.

Tresnawati, C., Aryanti, F., & Suhaerah, L. (2022). Flipped learning dalam meningkatkan berikir kritis mahasiswa pada materi fotosintesis dimasa pandemik covid-19. *Biosfer, Jurnal Biologi Dan Pendidikan Biologi*, *7*(7 No 1). https://doi.org/10.23969/biosfer.v7i1.5752

Tresnawati, C., Rahmat, A., & Rahman, T. (2024). Interactive digital teaching material konsep metabolise dalam meningkatkan kemampuan decision making dan problem solving. *Biosfer, Jurnal Biologi Dan Pendidikan Biologi*, *9*(2).

Van Meter, P., List, A., Lombardi, D., Kendeou, P., & (Eds). (2020). Handbook of learning from multiple representations and perspectives. In *Routledge (Tylor &Francis Group)*. Routledge. https://doi.org/10.4324/9780429443961

Wikanta, W., & Susilo, H. (2022). Higher order thinking skills achievement for biology education students in case-based biochemistry learning. *International Journal of Instruction*, *15*(4), 835–854. https://doi.org/10.29333/iji.2022.15445a